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Energy for economic growth, industrialization, environment and natural resources: Living with just enough

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ABSTRACT

This study investigates the causal relationship between energy consumption (i.e., nuclear energy consumption, electricity power consumption and fossil fuels energy consumption) and economic growth; energy consumption and industrialization (i.e., industrial GDP, beverages and cigarettes); energy consumption and environmental degradation (i.e., carbon dioxide emissions, population density and water resources); and finally, energy consumption and resource depletion (i.e., mineral depletion, energy depletion, natural depletion and net forest depletion) in Pakistan over a period of 1975–2011. The Granger causality (GC) test in the frequency domain using the Pierce framework has been employed. This GC test in the frequency domain relies on a modified version of the coefficient of coherence, which they estimate in a nonparametric fashion and for which they derive the distributional properties. The results infer that there exists uni-directional causality running from nuclear energy to industrial GDP, nuclear energy to water resources; and nuclear energy to carbon dioxide emissions but not vice versa. Similarly, electric power consumption Granger cause agriculture GDP but not other way around, further, there is a bi-directional causality running between electric power consumption to population density in Pakistan. Fossil fuel Granger cause industrial GDP and there is a bidirectional causality running between fossil fuel and population density. Moreover, the findings show that the nature of causality among nuclear energy consumption & agriculture; nuclear energy consumption & population density; electric power consumption & cigarettes production; fossil fuel & cigarettes; and fossil fuels and agriculture value added are in favour of the neutrality hypothesis in Pakistan. The conclusion has been strengthen and have a very strong implications in the context of Pakistan, where we have economic and financial constraints, and thus agreeing the bottom line, “living with the just enough”.

Contents

1. Introduction

In a recent article published in ‘Resilience’ written by Brown [7] for ‘The Global Oneness Project’ argued about the litany of challenges faces as a global species. The threats we face of scarcity

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which pit state against state and community against community, problems manmade and visible in nature i.e., growing population, increasing urbanization, deforestation, damaged watersheds, over consumption of resources, energy shortages, waste, pollution etc. We know there will be no easy fixes, no panaceas, but nevertheless as we try to set priorities and search for the most promising ways to approach these problems, many of us find ourselves looking to different studies, cultures and to earlier eras for inspirations. Many countries struggle to upgrade their energy systems to fully support current and future requirements of energy security and access, sustainability and economic growth. 'Energy for Society' is a global initiative program that aims to accelerate continuous improvement in the development of energy systems through the personal commitment of energy community leaders representing the oil and gas, utilities and technology, and renewable energy sectors [41].

Energy use has a variety of impacts. Energy extraction and processing always involve some forms of environmental disruption, including both geomorphological and ecological disruption as well as pollution. Energy use involves both pollution and other impacts, such as noise from transport, and land-use impacts, such as the construction of roads, etc [36]. As all human activities require energy use; in fact, all human impacts on the environment can be seen as the consequences of energy use [39]. Energy use is sometimes seen as a proxy for the environmental impact of human activity in general. Creating order in the economic system always implies creating disorder in nature, though this disorder could be in the sun or space rather than on Earth [40]. The factors that reduce the total amount of energy needed to produce a dollar's worth of GDP, therefore, also act to reduce the environmental impact of economic growth in exactly the same way as they reduce energy consumption. However, not all impacts of energy use are equally harmful to the environment and human health [36]. Hannesson [13] concludes that most of the world's primary energy comes from fossil fuels; it is going to be very difficult to reconcile reductions in carbon dioxide emissions with continued economic growth, especially in poor and medium rich countries.

According to IEA [15], the climate goal of limiting warming to 2 °C is becoming more difficult and costly with each year that passes, as if action is not taken before 2017, all the allowable CO_2 emissions would be locked-in by energy infrastructure existing in 2017. Fossil fuels are dominant in the global energy mix, supported by $523 billion subsidies in 2011, up almost 30% on 2010 and six times more than subsidies to renewables. Fossil energy use increased most in 2000–2008. Further, half of the increased energy use is coal, growing faster than all renewable energy. Since Chernobyl disaster in 1986, investments in nuclear power have been small. The volume of renewable energy is not yet substituting fossil energy use. Table 1 shows the energy used in fossils, nuclear and renewable world wide.

The depletion of natural resources has become a major focus of governments and organizations. This is evident in the UN's Agenda 21 Section Two, which outlines the necessary steps to be taken by countries to sustain their natural resources [38]. The depletion of natural resources is considered to be a sustainable development issue. The term sustainable development has many interpretations; most notably the Brundtland Commission's which wrap ups i.e., it is balancing the needs of the planet's people and species now and in the future [32]. Natural resource depletion is a concern for sustainable development as it has the ability to degrade current environments and potential to impact the needs of future generations [31].

During 2011–2012, energy outages in Pakistan continued to be the dominant constraint in its growth. Till the 1980s, less than two-third of the energy requirements were met through its own domestic resources. In the 1990s Pakistan was still engaged in various efforts to bridge the wide gap between increasing demand and limited energy supply. Further in the early 2000s, the energy sector (especially its sub sector electricity) received greater attention because of the faster rate of growth in its demand. By 2011–2012, electricity and gas shortages are considered to be the primary cause of constrained production activities in a number of industries. Energy intensive industries (Petroleum, Iron and Steel, Engineering Industries and Electrical) shaved off 0.2 percentage points from real GDP growth in 2010–2011 and in 2011–2012. Also, the estimated cost of power crises to the economy is around 2% of GDP, while the cost of subsidies given to the power sector to the exchequer in the last four years (2008–2012) is almost 2.5% of GDP. The liquidity crunch in the power sector has resulted in under utilization of installed capacity of up to 4000 MW. It has also affected investment in power sector [22].

As of 2012, nuclear power in Pakistan is provided by three licensed-commercial nuclear power plants [21]. Pakistan is the first Muslim country in the world to construct and operate civil nuclear power plants. The Pakistan Atomic Energy Commission (PAEC), the scientific and nuclear governmental agency, is solely responsible for operating these power plants. As of 2012, the electricity generated by commercial nuclear power plants constitutes roughly 3.6% of electricity generated in Pakistan, compared to approximately 62% from fossil fuel, 33% from hydroelectric power and 1.4% from Coal electricity [28]. Pakistan is one of the four nuclear armed states (along with India, Israel, and North Korea) that is not a party to the Nuclear Non-Proliferation Treaty but is a member in good standing of the International Atomic Energy Agency. Table 2 shows the details of nuclear power reactors working in Pakistan.

Per capita income imbeds a wide range of fluctuations behind the number, but still regarded as one of the foremost indicators of the depth of growth and general well-being of an economy. The historical importance and simplicity of per capita income as a measure of the average level of prosperity in an economy is well established. The per capita income of Pakistan in dollar terms has increased from $576 in 2002–03 to $1254 in 2010–11. The main factors responsible for the sharp rise in per capita income include higher growth in nominal GDP, stable exchange rate and a four-fold increase in the inflows of workers' remittances. Fig. 1 shows the improvement in per capita income during the last eleven years. The per capita income is reflecting the impact of recent economic slowdown.

Energy is needed for all sectors of the economy, and therefore, an energy policy has to take into account the requirements of the household, transport, agricultural and other sectors, as well as the industrial sector. Current environmental problems associated with agriculture inter-alias include land degradation due to erosion, use of agro-chemicals, water logging and salinity, depletion of forest and water resources. In this study an analysis has been carried out to find a statistical relationship among energy factors (i.e., nuclear energy consumption, electricity power consumption, fossil fuel energy consumption); industrialization (i.e., industrial

Table 1
Global energy used (TW h) in fossils, nuclear and renewable energy.

	Fossil	Nuclear	Renewable	Total
1990	83,374	6,113	13,082	102,569
2000	94,493	7,857	15,337	117,687
2008	117,076	8,283	18,492	143,851
Change 2000–2008	22,583	426	3,155	26,164

Note: IEA [15].

Table 2
Pakistan nuclear power reactors.
Source: PNRA [26].

Nuclear power reactors	Type	Location	Net capacity (MWe)	Gross capacity (MWe)	Construction start	Connected to grid	Commercial operation
CHASNUPP-I	PWR	Chasma, Punjab Province	300	325	1 August 1993	13 June 2000	15 September 2000
CHASNUPP-II	PWR	Chasma, Punjab Province	300	325	28 December 2005	14 March 2011	20 May 2011
CHASNUPP-III	PWR	Chasma, Punjab Province	300	330	28 April 2009	2016	N/A
CHASNUPP-IV	PWR	Chasma, Punjab Province	300	330	2011	2017	N/A
KANUPP-I	PHWR	Paradise Point, Karachi, Sindh Province	125	137	1 August 1966	18 October 1971	7 December 1972
KANUPP-II	PHWR	Paradise Point, Karachi, Sindh Province	600	N/A	Preliminary work started but then the project was put on hold in 2009.	N/A	N/A
KANUPP-III	PHWR	Paradise Point, Karachi, Sindh Province	400	N/A	Designing of reactor is completed. But the construction has not yet started	N/A	N/A

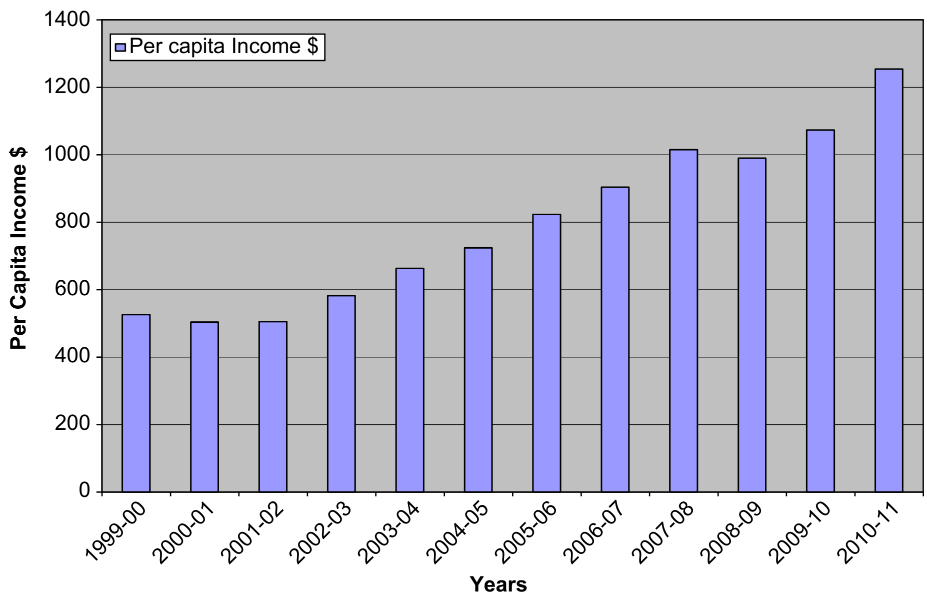

Fig. 1. Per capita income of Pakistan (in US $).
Source: Pakistan Economic Survey [22].

growth, beverages, cigarettes); economic growth (i.e., GDP, agriculture growth, manufacturing, services); environmental factors i.e., (carbon dioxide emissions, population density, water resources); and resource factors (i.e., mineral depletion, energy depletion, natural depletion, net forest depletion) in the context of Pakistan. Keeping in view the above discussion, the objectives of the study is as follows i.e.,

- Whether the statistical relationship between the energy and economic factors in Pakistan is uni-directional (i.e., energy factors affect/cause economic factors or economic factors affect/cause energy factors);
- Whether the statistical relationship between the energy and economic factors in Pakistan is bi-directional (i.e., energy factors affect/cause economic factors and economic factors affect/cause energy factors);
- The two variables (energy and economic factors) do not influence each other (causality independent).

These objectives have been achieved with the Granger causality test in the frequency domain using the Pierce framework. The study is organized as follows: after introduction which is provided in Section 1, literature review is carried out in Section 2. Data source and methodological framework is explained in Section 3. The estimation and interpretation of results is mentioned in Section 4. Section 5 concludes the paper.

2. Review of literature

The relationship between energy consumption and economic growth is now well established in the literature, yet the direction of causation of this relationship remains controversial i.e., whether economic growth leads to energy consumption or that energy consumption is the engine of economic growth. The direction of causality has significant policy implications [3]. Soytas and Sari [35] re-examines the causality relationship between energy consumption and GDP in the top 10 emerging markets and G-7 countries. The results discover bi-directional causality in Argentina, causality running from GDP to energy consumption in Italy and Korea, and from energy consumption to GDP in Turkey, France, Germany and Japan. Ref. [18] examines the causal relationship between energy consumption and real GDP within a multivariate framework for 16 Asian countries including two cross-regional groups, namely the APEC and ASEAN groups during the 1971–2002 periods. The empirical results fully support a positive

long-run cointegrated relationship between real GDP and energy consumption when the heterogeneous country effect is taken into account. It is found that although economic growth and energy consumption lack short-run causality, there is long-run unidirectional causality running from energy consumption to economic growth.

Asafu-Adjaye [4] estimates the causal relationships between energy consumption and income for India, Indonesia, the Philippines and Thailand, using cointegration and error-correction modelling techniques. The results indicate that, in the short-run, unidirectional Granger causality runs from energy to income for India and Indonesia, while bidirectional Granger causality runs from energy to income for Thailand and the Philippines. Ozturk et al. [20] use the panel data of energy consumption and economic growth for 51 countries from 1971 to 2005. The empirical results suggest that energy consumption and GDP are cointegrated for all three income group countries. Further, the panel causality test reveal that there is long-run Granger causality running from GDP to energy consumption (EC) for low income countries and there is bidirectional causality between EC and GDP for middle income countries.

Chu and Chang [9] apply bootstrap panel Granger causality to test whether energy consumption promotes economic growth using data from G-6 countries over the period of 1971–2010. The results reveal that nuclear consumption causes economic growth in Japan, the UK, and the US; economic growth causes nuclear consumption in the US; nuclear consumption and economic growth show no causal relation in Canada, France and Germany. There is one-way causality from economic growth to oil consumption only in the US, and that oil consumption does not Granger cause economic growth in G-6 countries except Germany and Japan. Ishida [16] analyzes cointegration and causality between fossil fuel consumption and economic growth in the world over the period 1971–2008. The results indicate that fossil fuel consumption and GDP are cointegrated and there exists long-run unidirectional causality from fossil fuel consumption to GDP.

Apergis and Payne [2] determine the Granger-causal relationship between renewable and non-renewable electricity consumption and economic growth for South America. The Granger-causality results indicate bidirectional causality between renewable and non-renewable electricity consumption, respectively, and economic growth in both the short-run and long-run. Hu and Lin [14] examine the long-run equilibrium relationship between economic growth and energy consumption growth in Taiwan. The results indicate that economic growth is non-linearly cointegrated with energy consumption when the asymmetric adjusting behaviour is confirmed in Taiwan. Chang et al. [8] examine ‘growth, conservation, neutrality or feedback' hypotheses in 12 Asian countries for the period 1970 to 2010. The result support evidence on the direction of causality and is consistent with the neutrality hypothesis in two-thirds of these 12 Asian countries. Growth hypothesis and conservation hypothesis hold for India and Philippines, respectively. However, a feedback was found for both Thailand and Vietnam.

Aslan and Cam [5] examine the causal relationship among nuclear energy consumption, economic growth, capital and labor for Israel, over the period of 1985–2009 using a bootstrap-corrected causality. It is found that there exists unidirectional causality running from nuclear energy to GDP. Sadorsky [30] uses heterogeneous panel regression estimators to model the impact that income, urbanization and industrialization has on energy intensity for a panel of 76 developing countries. The results show that, in the long-run, a 1% increase in income reduces energy intensity by −0.45% to −0.35%. Long-run industrialization elasticities are in the range 0.07 to 0.12. Kapusuzoglu and Karan [17] examine the causal relationships between the energy consumption and economic factors, for 30 developing countries over a period of 1971–2007. The results reveal common relationships in various directions between energy consumption and the other factors.

Yu et al. [43] report China's eco-efficiency trends and the cause of their dynamic behaviour during the period 1978–2010. The results show that in general, eco-efficiency indicators increased for resource utilization, energy consumption and emissions for air and water, and relative decoupling occurred in China at a high level in the global context. Further, decoupling from economic growth has been absolute for the discharge of soot, chemical oxygen demand (COD) and ammonia nitrogen. Zhang et al. [44] analyze the interactions among China's economic growth and energy consumption and emissions during 1978–2007. The results show that energy consumption and emissions' impact rise simultaneously. Therein, non-renewable energy resources possess absolute share in total energy consumption and undertake primary responsibility for increasing emissions' impact, and NH_3–N in wastewater leads to the most emissions' impact on environment. Peura [24] considers macro level theories for understanding the urge for reform as well as the process of societal change both in general terms, and more specifically within the energy sector. The study reviews and discusses humankind's limits of existence and dialectics of the human–nature relationship by contrasting Malthusian and Boserupian theoretical views. The result conclude that the production of energy has traditionally been one of the core issues concerning the effect humankind has on the environment, and with regards to potential change related to it, reforming the energy sector is in a key position.

Ahmad et al. [1] investigate the impact of population & industrial growth CO_2 emissions in selected SAARC countries over a period of 1980 to 2008. Results of the study show that industrialization and population both were major causes of air pollution in these SAARC countries. Shahbaz et al. [33] examine the relationship of natural gas consumption and economic growth in Pakistan over a period of 1972–2010. Result shows the existence of long-run relationship among the variables. Natural gas consumption, capital, labor and exports are positively affecting economic growth in Pakistan. Examines the impact of electricity production on economic growth in Pakistan over a period of 1975–2010. The rsult finds bidirectional causal relationship between the variables in the long run whereas no causal relationship is found in the short run. Sabir et al. [29] examine the growth trends of electricity consumption in the industrial sector of Pakistan and its demand function. Results showed that with an increase in price of electricity and oil, the demand for electricity tends to decrease. Moreover, the industrial share in GDP was positively related with electricity demand in the country.

On the basis of above discussion, the study concludes that the relationship between energy and growth has mainly based upon either on direct observation of the data or on some parallel based analyses. Such approaches are clearly insufficient to classify the nature of the underlying linkage between energy consumption and economic factors. Moreover, such analyses failed to distinguish between four alternative but equally plausible hypotheses, each with different policy implications. These are: (i) energy factors (i.e., nuclear energy, electricity power consumption and fossil fuel energy) cause economic factors (i.e., industrialization, economic growth, environmental degradation and natural resource depletion), (ii) economic factors cause energy factors, (iii) There is a bi-directional causality between the two variables and (iv) Both variables are causality independent (although highly correlated).

Both energy and economic factors have been escalating in Pakistan, hence there is a pressing need to evaluate and analyze the energy and economic factors nexus and to find out the inter

relationship. In the subsequent sections an effort has been made to empirically find out the casual relationship between energy factors and economic factors in the context of Pakistan.

3. Data source and methodological framework

The annual time series data is employed for the Pakistan economy for the period of 1975–2011. All relevant data comes from World Development Indicators which is published by World Bank [42]. The study investigates the impact of four macroeconomic variables i.e., industrialization, economic growth, environmental degradation, and resource depletion on energy demand of Pakistan as shown in Fig. 2. Each variable has further sub-classifications i.e., industrialization comprises industrial GDP, beverages and cigarettes; economic growth comprises GDP, agriculture, manufacturing and services sectors growth; environmental proxies comprises CO_2 emission, population density and water resources; resource depletion includes mineral depletion, energy depletion, natural depletion and net forest depletion and finally nuclear energy consumption, electric power consumption and fossil fuel energy consumption are used as a proxy for energy demand.

The link of each macroeconomic variable with energy demand is treated separately. The idea is to explore the cause and effect relationship for each of the underlying variable, in this context we use the frequency domain approach to test the null hypothesis given in Table 3 for four different models.

Where, NE represents nuclear energy consumption (% of total energy use); EPC represents electric power consumption (kW h per capita); FF represents fossil fuel energy consumption (% of total); IG represents industry, value added (current US$); BEV represents beverages (000 doz Bottles); CIG represents cigarettes (million Nos); CO_2 represents carbon dioxide emissions (kt); PD represents population density (people per sq. km of land area); WR represents improved water source (% of population with access); AGR represents agriculture, value added (% of GDP); MS represents Manufacturing, value added (current US$); END represents energy depletion (current US$); ND represents natural resources depletion (% of GNI); and NFD represents net forest depletion (current US$).

3.1. Econometric model

The investigation of the causal relationship between energy use and economic activity is valuable for an appraisal of potentially conflicting policy objectives, such as the trade-off between energy conservation and economic growth. There are four alternative economic hypotheses regarding the causal mechanisms underlying the energy consumption–economic growth nexus, which are currently heavily under debate in the energy economics literature (see [23]).

Analysing time series in frequency domain i.e. spectral analysis could be helpful in supplementing the information obtained by time-domain analysis [12] and Priestley, [27]). Spectral analysis highlights the cyclical properties of data. In our study, we follow the bivariate GC test over the spectrum proposed by Lemmens et al. [19]. They have reconsidered the original framework proposed by Pierce [25], and proposed a testing procedure for Pierce's spectral GC measure. This GC test in the frequency domain relies on a modified version of the coefficient of coherence, which they estimate in a nonparametric fashion and for which they derive the distributional properties.

To assess the causality between any two stochastic processes, one usually refers to the concept of Granger causality (GC). GC explains the extent to which one process is leading another process and builds upon the notion of incremental predictability. A wide range of bivariate GC tests exists which can be used to evaluate the presence and/or direction of the causality of any two macroeconomic variables. Although traditional approaches to GC yielded interesting facts, however they ignore the possibility that the strength and/or direction of the GC – if any – could vary over different frequencies. The idea of further disentangling the Granger causality relationship between two time series was first suggested by Granger [12]. Then,

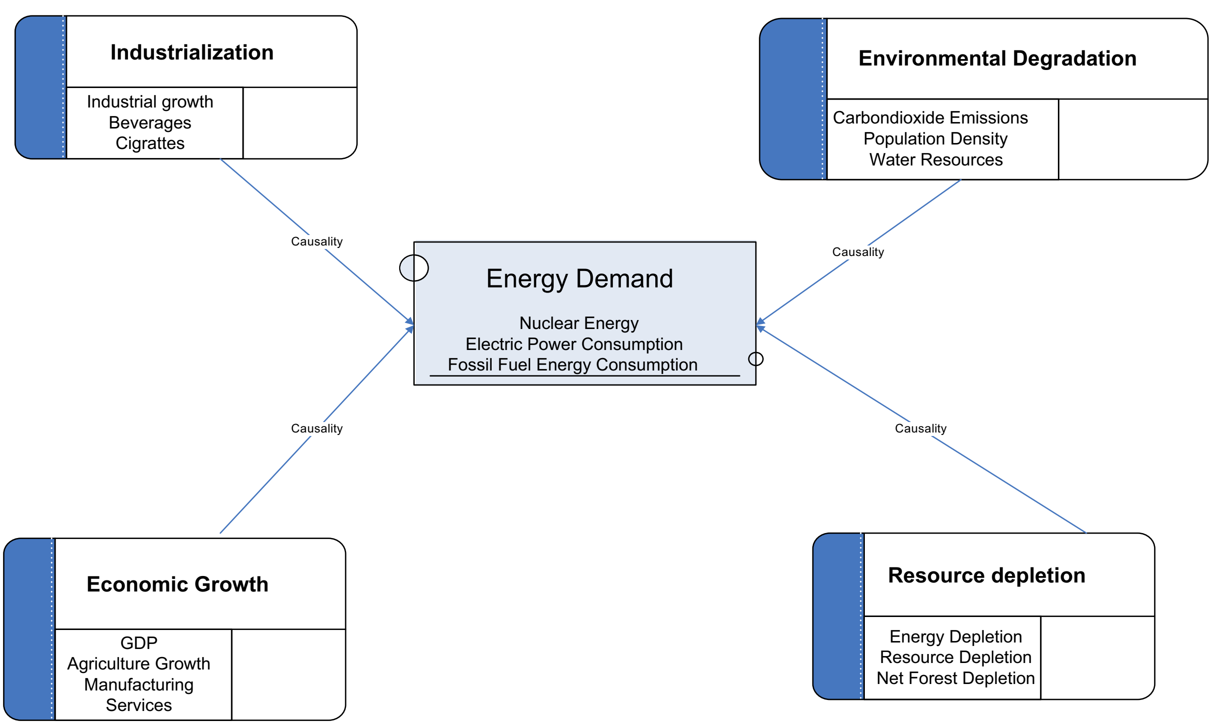

Fig. 2. Research framework of the study. .
Source: Self extract

Table 3
Null hypothesis for Granger causality.

Model 1: Industrialization and energy demand	Model 2: Environmental degradation and energy demand
Industrial growth and energy demand	**Carbon dioxide emissions and energy demand**
log(IG) does not Granger causes log(NE)	log(CO_2) does not Granger causes log(NE)
log(NE) does not Granger causes log(IG)	log(NE) does not Granger causes log(CO_2)
log(IG) does not Granger causes log(EPC)	log(CO_2) does not Granger causes log(EPC)
log(EPC) does not Granger causes log(IG)	log(EPC) does not Granger causes log(CO_2)
log(IG) does not Granger causes log(FF)	log(CO_2) does not Granger causes log(FF)
log(FF) does not Granger causes log(IG)	log(FF) does not Granger causes log(CO_2)
Beverages and energy demand	**Population density and energy demand**
log(BEV) does not Granger causes log(NE)	log(PD) does not Granger causes log(NE)
log(NE) does not Granger causes log(BEV)	log(NE) does not Granger causes log(PD)
log(BEV) does not Granger causes log(EPC)	log(PD) does not Granger causes log(EPC)
log(EPC) does not Granger causes log(BEV)	log(EPC) does not Granger causes log(PD)
log(BEV) does not Granger causes log(FF)	log(PD) does not Granger causes log(FF)
log(FF) does not Granger causes log(BEV)	log(FF) does not Granger causes log(PD)
Cigarettes and energy demand	**Water resources and energy demand**
log(CIG) does not Granger causes log(NE)	log(WR) does not Granger causes log(NE)
log(NE) does not Granger causes log(IG)	log(NE) does not Granger causes log(WR)
log(IG) does not Granger causes log(EPC)	log(WR) does not Granger causes log(EPC)
log(EPC) does not Granger causes log(IG)	log(EPC) does not Granger causes log(WR)
log(IG) does not Granger causes log(FF)	log(WR) does not Granger causes log(FF)
Model 3: Economic growth and energy demand	**Model 4: Resource depletion and energy demand**
GDP and energy demand	**Energy depletion and energy demand**
log(GDP) does not Granger causes log(NE)	log(END) does not Granger causes log(NE)
log(NE) does not Granger causes log(GDP)	log(NE) does not Granger causes log(END)
log(GDP) does not Granger causes log(EPC)	log(END) does not Granger causes log(EPC)
log(EPC) does not Granger causes log(GDP)	log(EPC) does not Granger causes log(END)
log(GDP) does not Granger causes log(FF)	log(END) does not Granger causes log(FF)
log(FF) does not Granger causes log(GDP)	log(FF) does not Granger causes log(END)
Agricultural growth and energy demand	**Natural depletion and energy demand**
log(AGR) does not Granger causes log(NE)	log(ND) does not Granger causes log(NE)
log(NE) does not Granger causes log(AGR)	log(NE) does not Granger causes log(ND)
log(AGR) does not Granger causes log(EPC)	log(ND) does not Granger causes log(EPC)
log(EPC) does not Granger causes log(AGR)	log(EPC) does not Granger causes log(ND)
log(AGR) does not Granger causes log(FF)	log(ND) does not Granger causes log(FF)
log(FF) does not Granger causes log(AGR)	log(FF) does not Granger causes log(ND)
Manufacturing services and energy demand	**Net forest depletion and energy demand**
log(CIG) does not Granger causes log(NE)	log(NFD) does not Granger causes log(NE)
log(NE) does not Granger causes log(IG)	log(NE) does not Granger causes log(NFD)
log(IG) does not Granger causes log(EPC)	log(NFD) does not Granger causes log(EPC)
log(EPC) does not Granger causes log(IG)	log(EPC) does not Granger causes log(NFD)
log(IG) does not Granger causes log(FF)	log(NFD) does not Granger causes log(FF)
log(FF) does not Granger causes log(IG)	log(FF) does not Granger causes log(NFD)

Pierce [25] proposed an *R*-squared measure for time series and decomposed it over each frequency of the spectrum, resulting in a measure for GC at every given frequency. The idea was that a spectral-density approach would give a richer and more comprehensive picture than a one-shot GC measure that is supposed to apply across all periodicities i.e. in the short run, over the business-cycle frequencies, and in the long run (see Lemmens et al. [19]). For example, the GC between macroeconomic conditions and electrical usage would be most prominent at business-cycle frequencies [37]. Breitung and Candelon [6] analyzed at which frequencies the interest rate spread has predictive power for the real economic growth. Coudert et al. [10] argued that the supply and demand elasticity of oil prices tend to differentiate from short- to long run etc.

4. Empirical results

First of all stationarity properties of all variables have been tested through Augmented Dickey–Fuller (ADF) unit root test in Table 4.

Table 4 reports that all variables have unit root problem at 1% and 5% level of significance in their level form, while they are stationary at their first differenced form. The Pearson's correlation analysis is also conducted to see the pair wise correlation of energy demand with Economic growth, industrialization, environmental degradation and resource depletion. Table 5 indicates that there is a significant relationship exists among most of the variables. This indicates to explore the Granger causality running from energy demand to all other variables.

The next step is to consider the returns (i.e. natural logarithm of first order differenced series) of all variables have been filtered using ARMA models to obtain the innovation series. Below we present the Granger causality results between economic growth and energy demand, industrialization and energy demand, environmental degradation and energy demand and finally resource depletion and energy demand using the innovation series after ARMA. We have used lag length [1] $M=\sqrt{T}$. The frequency (λ) on the horizontal axis can be translated into a cycle or periodicity of T years by $T=2\pi/\lambda$ where T is the period. After ARMA filtering the series and adjusting for lags, we are left with 37 observations.

[1] Following Diebold [11] we take M equal to the square root of number of observations T.

Table 4
p-value of the ADF test on levels and first differences of the variables (1975–2011).

	Industrialization			**Environmental degradation**			**Energy demand**		
Variables	Ln(IG)	Ln(BEV)	Ln(CIG)	Ln(PD)	Ln(WR)	Ln(Co2)	Ln(NE)	Ln(EPC)	Ln(FF)
Level	0.6830	0.8654	0.9280	0.9928	0.2730	0.9715	0.3410	0.1835	0.3124
1st Diff.	0.0003**	0.0000**	0.000**	0.0423*	0.0000**	0.0006**	0.000**	0.0000**	0.0000**
	Economic growth			**Resource depletion**					
Variables	Ln(GDP)	Ln(AGR)	Ln(MS)	Ln(END)	Ln(ND)	Ln(NFD)			
Level	0.6364	0.8865	0.8310	0.7230	0.4940	0.9761			
1st Diff.	0.0003**	0.0001**	0.0002**	0.000**	0.000**	0.000**			

Note: The null hypothesis is that the series is stationary or contains a unit root. The rejection of the null hypothesis is based on *p*-value less than 0.01 or 0.05 for 1% and 5% level of significance. *and **denote the significance at 5% and 1% level of significance, respectively.

Table 5
Pair-wise correlation of the variables (1975–2011).

	Industrialization			**Environmental degradation**			**Economic growth**		
Energy demand	Ln(IG)	Ln(BEV)	Ln(CIG)	Ln(PD)	Ln(WR)	Ln(CO_2)	Ln(GDP)	Ln(AGR)	Ln(MS)
Ln(NE)	0.5397	0.4719	0.2785	0.5529	0.5516	−0.2202	0.5412	−0.6282	0.5498
Ln(EPC)	0.9517	0.9016	0.7936	0.9852	0.9878	−0.2379	0.9519	−0.9150	0.9469
Ln(FF)	0.9417	0.8814	0.7674	0.9804	0.9825	−0.0627	0.9422	−0.8841	0.9333
	Resource depletion								
Energy demand	Ln(ED)	Ln(ND)	Ln(NFD)						
Ln(NEN)	0.5126	0.2684	0.3999						
Ln(EPC)	0.8679	0.5596	0.8814						
Ln(FF)	0.8487	0.5253	0.8755						

Therefore, we consider the shortest possible cycle of 2 years and longest cycle of 36 years.

Fig. 3 shows that for each of the three variables i.e. GDP, agricultural growth and manufacturing services which are used as a proxy for economic growth and the three variables i.e. nuclear energy, electric power consumption and fossil fuel energy consumption which are used as a proxy for energy demand. Granger coefficient of coherence using the Pierce framework is used for causality analysis. This coefficient assesses, whether and to what extent the energy demand are Granger causing the economic growth at that frequency or vice versa. The results depicts that the higher the Granger coefficient of coherence, the higher the Granger causality at that particular frequency.

Fig. 3 shows insignificant impact of nuclear energy on agricultural growth of Pakistan, whereas in case of GDP the Granger coefficient of coherence reaches the 5% significance level but it does not crosses the significance line, which implies that the impact of nuclear energy on GDP is also insignificant. However in case of manufacturing services, at frequencies corresponding to 8 to 36 years cycle, we find nuclear energy significantly Granger causes manufacturing services of Pakistan. The Granger coefficient of coherence attains the maximum value at frequency corresponding to 36 years. It implies that nuclear energy provides significant predictive power for long run future manufacturing services movement. Fig. 3 further indicates that the causality running from electricity power consumption to all three proxy variables for economic growth is significant at different frequencies. It implies that the electricity power consumption plays a significant role in economic growth of Pakistan. Granger causality running from electricity power consumption to GDP is significant corresponding to 2–3 years which reflect short-run cycle. The Granger causality running from electricity power consumption to agriculture is significant corresponding to 3–8 years reflecting medium-run cycle. It implies that electricity power consumption provides significant predictive power for future growth movement of agriculture sector within 3–8 years band. In case of manufacturing and services sector, electricity power consumption Granger causing in the short and in the medium-run. The duration of the short run cycle is around 2–2.5 years, whereas the duration of the medium-run cycle is around 4–8 years. However, the coefficient of coherence attains the maximum value at the frequency corresponding to 2.5 years. The short run cycles dominates the medium-run cycle in terms of estimated Granger coefficient of coherence. Thus predictive power of electricity power consumption for future manufacturing services movement is more in the short run. Likewise nuclear energy, Fig. 3 indicates that the impact of fossil fuel energy on agricultural growth and GDP is insignificant. However the impact of fossil fuel energy on manufacturing services of Pakistan is significant corresponding to 2.5 to 6 years cycle reflecting medium-run cycle. Overall Fig. 3 suggests that among three variables used as a proxy to measure energy demand, the electricity power consumption is the most relevant variable as it significantly impact all three variables of economic growth. However the impact of nuclear energy and fossil fuel energy on manufacturing services in the long run and medium run, respectively, is also justified. The results are consistent with the previous study of Chu and Chang [9], where nuclear energy Granger cause economic growth variables in the long-run. One interesting finding of the results is that all three proxy variables of energy demand Granger causes the manufacturing services Industry of Pakistan in short, medium or in the long run. The result is consistent with [18] and Chang et al. [8], both studies confirm the growth and conservation hypothesis among the developed and developing countries.

On the other side, there is an insignificant impact of GDP on nuclear energy and electricity power consumption of Pakistan. This implies that there exists uni-directional relationship between GDP and electricity power consumption (EPC) running from EPC to GDP and no relationship between GDP and nuclear energy of Pakistan. In the case of fossil fuel energy, GDP Granger causes fossil fuel energy corresponding to 2–3 years cycle. This again indicates the uni-directional relationship running from GDP to fossil fuel energy. The impact of agriculture growth on the nuclear energy, electricity power consumption and the fossil fuel energy is

insignificant at all frequencies. This implies that there is no causal relationship between nuclear energy and agricultural growth or fossil fuel energy and agricultural growth. However there exists a uni-directional relationship running from electricity power consumption to agricultural growth in the medium-run. The behaviour of Granger causality running from manufacturing sectors to all three proxy variables of economic growth is similar to Granger causality running from agricultural growth to economic growth. In case of Granger causality running from manufacturing services to fossil fuel energy, the coefficient of coherence reaches the significance level corresponding to 4.5 years but it does not crosses the significance line which implies that the impact of manufacturing services to fossil fuel energy is insignificant. We conclude that there exists a unidirectional relationship of energy demand to manufacturing services of Pakistan at different frequencies.

Similarly, Fig. 4 shows that for each of the three variables i.e. carbon dioxide emissions (CO_2), population density (PD) and water resources (WR) which are used as a proxy for environmental degradation and the three variables i.e. nuclear energy (NE), electric power consumption (EPC) and fossil fuel energy consumption (FF) which are used as a proxy for energy demand, Granger coefficient of coherence using the Pierce framework. This coefficient assesses, whether and to what extent the energy demand are Granger causing the environmental degradation at that frequency or vice versa.

Fig. 4 indicates an insignificant impact of nuclear energy on population density of Pakistan, whereas in case of carbon dioxide emissions the Granger coefficient of coherence is significant corresponding to 4–6 years cycle reflecting the short duration cycle. The Granger coefficient of coherence from nuclear energy to water resources just crosses the 5% significance level corresponding to 6–8 years cycle, which means that there is little impact of nuclear energy on water resources. However in case of electric power consumption, at frequency corresponding to five years Granger coefficient reaches the 5% significance level but does not crosses the line which indicates that impact of electric power consumption on carbon dioxide emissions is insignificant. We find electric power consumption significantly Granger causes population density of Pakistan in the short and long-run. The Granger coefficient of coherence attains the maximum value at frequency corresponding to 2 years and remains significant till 3.5 years, which indicates short-run cycle. The Granger causality is also significant between the frequencies corresponding to 4.5–10 years cycle. It implies that electric power consumption provides significant predictive power for short and long run movement of population density. The impact of electric power consumption on water resources is insignificant at all different frequencies. In the case of fossil fuel energy consumption, we find little impact of fossil fuel energy consumption on carbon dioxide emissions corresponding to 4–4.5 years cycle. The behaviour of Granger causality running from fossil fuel energy consumption to population density is similar to the electric power consumption to population density. We find fossil fuel energy consumption significantly Granger causes population density of Pakistan in the short, medium and even in the long run.

The Granger coefficient of coherence remains significant at all frequencies higher than 0.5. This clearly indicates the rejection of the null hypothesis of no causality running from fossil fuel energy consumption to population density and implies the significance

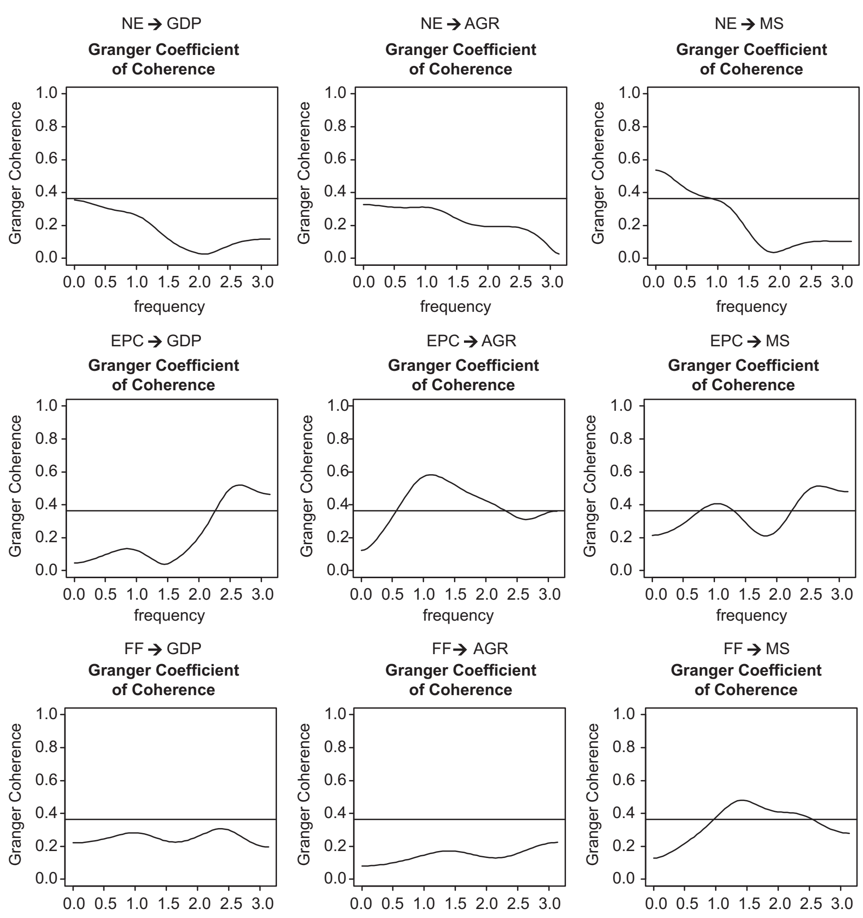

Fig. 3. Granger coefficient of coherence from energy demand to economic growth and economic growth to energy demand using the Pierce framework. *Note*: The solid line represents the critical value at the 5% level for the test for no GC.

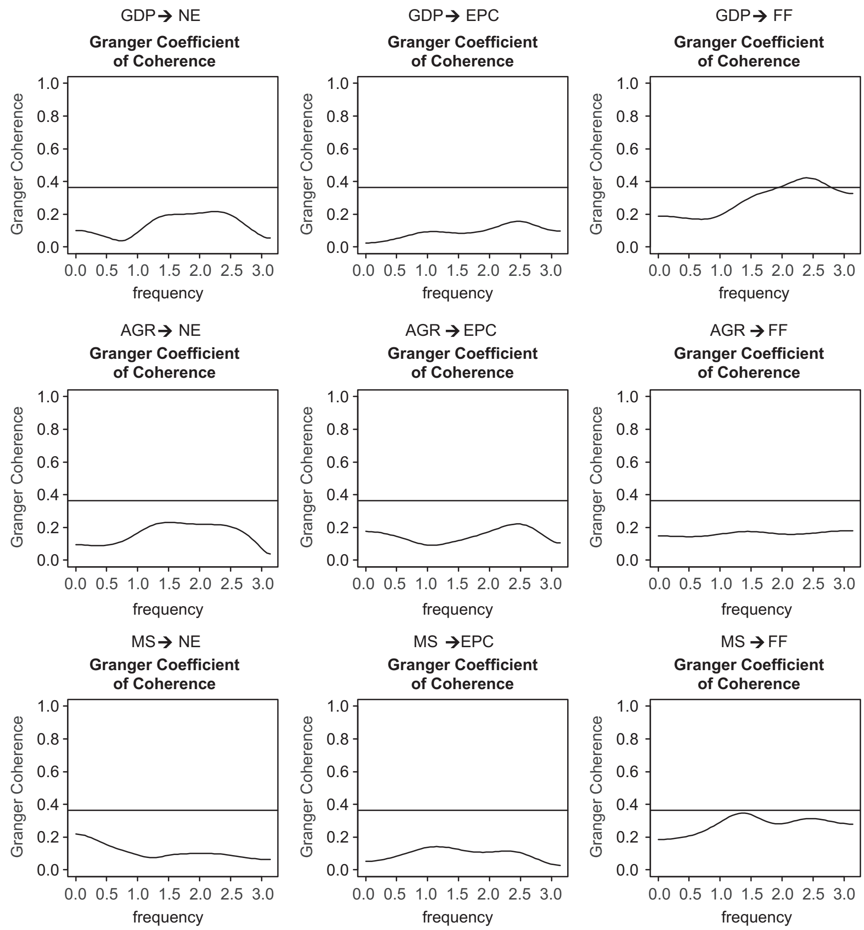

Fig. 3. (*continued*)

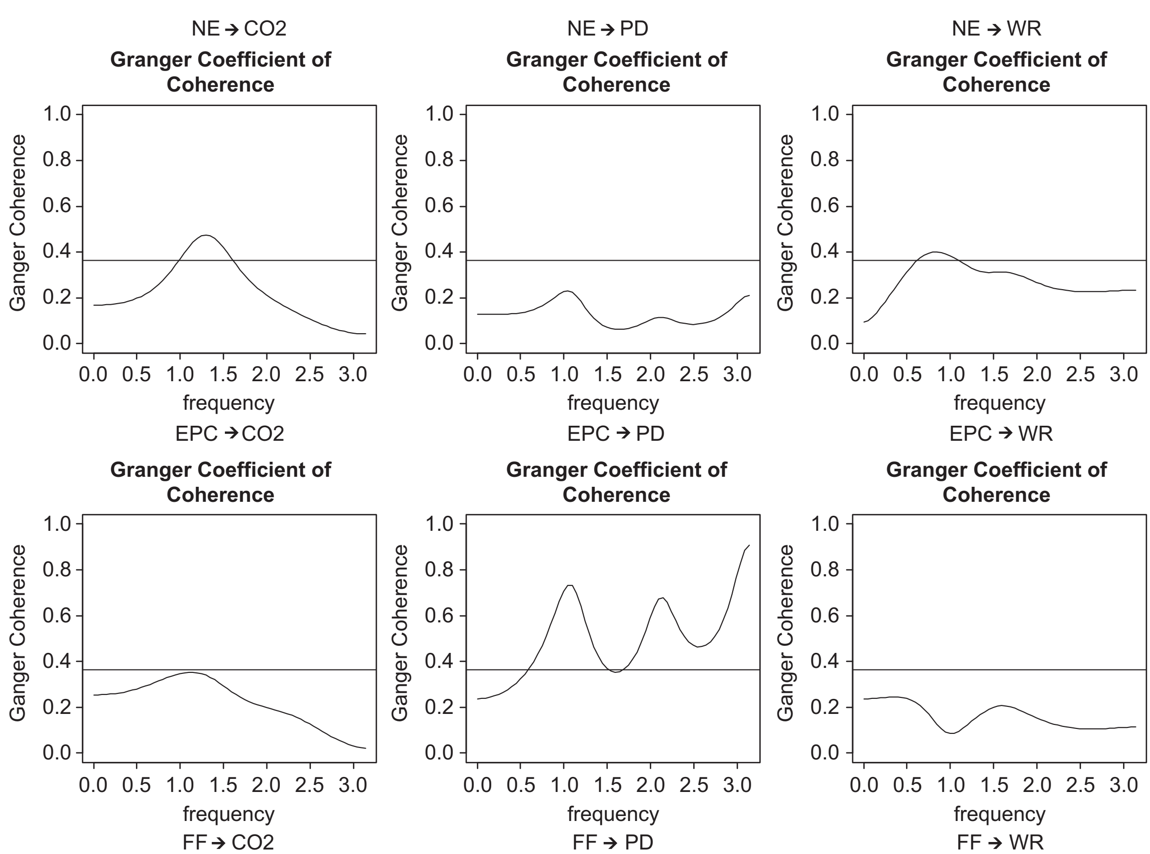

Fig. 4. Granger coefficient of coherence from energy demand to environmental degradation and environmental degradation to energy demand, using the Pierce framework. *Note*: The solid line represents the critical value at the 5% level for the test for no GC.

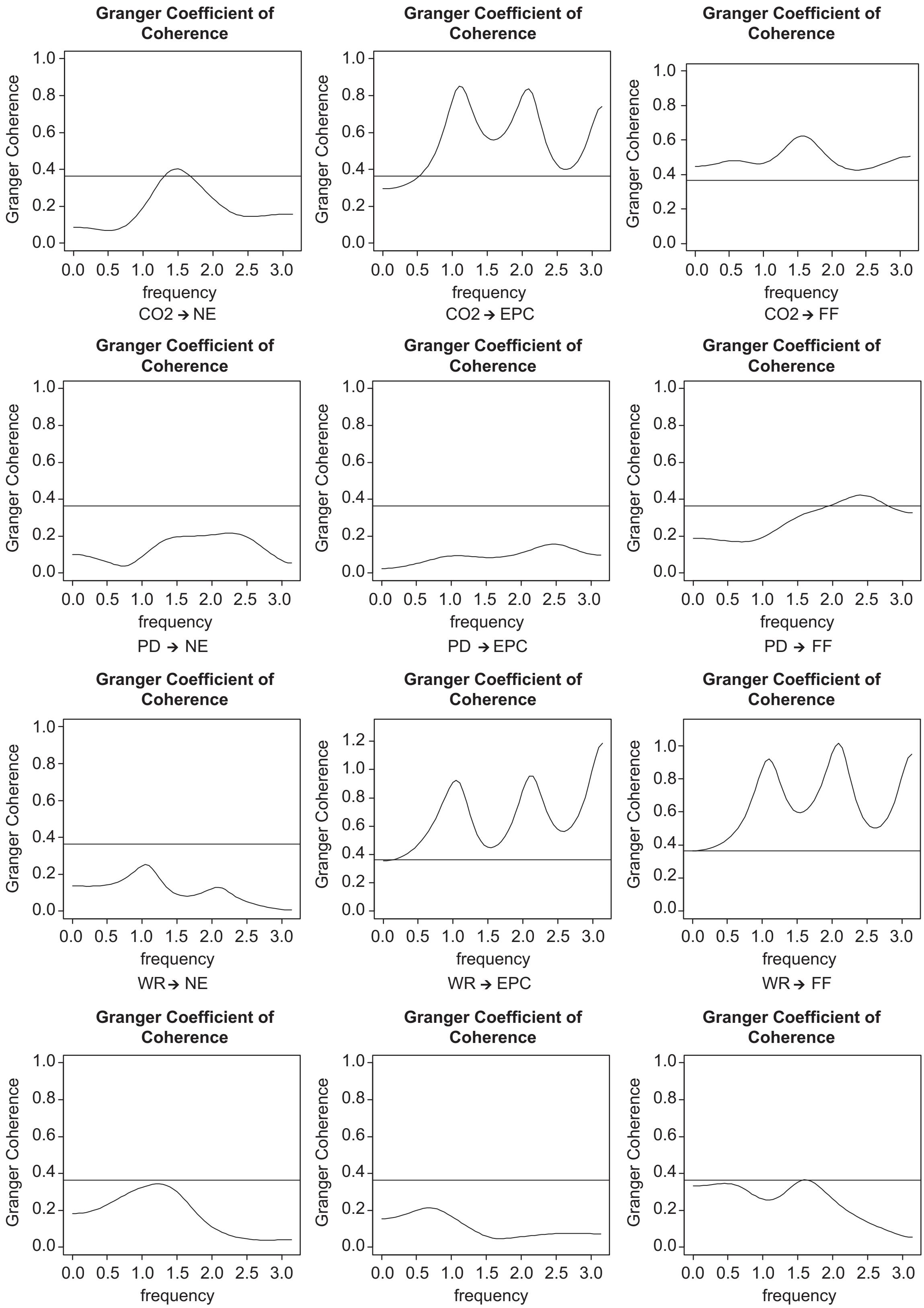

Fig. 4. (*continued*)

corresponding to 2–10.5 years cycle. Likewise electric power consumption, fossil fuel energy consumption can also provides significant predictive power for future movement of population density. The Granger causality running from fossil fuel energy consumption to water resources is significant at all different frequencies. Although the Granger coefficient of coherence attains the maximum of 0.6 corresponding to 4 years cycle, but as it is above the 5% significance level throughout which implies that fossil fuel energy consumption can also provide significant predictive power for future movement of water resources too.

Further, Fig. 4 indicates the reverse causality i.e. at what extent the environmental degradation are Granger causing the energy demand at a particular frequency. There is an insignificant impact of carbon dioxide emissions on nuclear energy and electricity power consumption of Pakistan. This implies that there exists weak uni-directional relationship between nuclear energy and carbon dioxide emissions running from NE to CO_2 and no relationship between carbon dioxide emissions and electric power consumption of Pakistan. In case of fossil fuel energy consumption, carbon dioxide emissions Granger causes fossil fuel energy corresponding to 2 to 3 years cycle reflecting short-run cycle. This implies that there exists weak bi-directional relationship between carbon dioxide emissions and fossil fuel energy consumption. The impact of population density on the nuclear energy is insignificant at all frequencies. This implies that there is no causal relationship between nuclear energy and population density. However population density significantly Granger causes electric power consumption and fossil fuel energy consumption at all different frequencies. This implies that there exists strong bidirectional relationship between population density and electric power consumption and population density and fossil fuel energy consumption, respectively. Likewise CO_2, the impact of water resources on nuclear energy and electric power consumption is insignificant at all different frequencies. This implies that there exists weak unidirectional relationship running from nuclear energy to water Resources and no relationship between water resources and electric power consumption. Though, the Granger coefficient of coherence jumps at frequencies corresponding to 4 years cycles but does not cross the significance level. Therefore we cannot reject the null hypothesis of no causality running from water resources to fossil fuel energy consumption. Hence there exists significant uni-directional relationship running from fossil fuel energy to water resources. Overall, the result suggests that among all variables the most significant relationship exists between population density and electric power consumption and population density and fossil fuel energy consumption, respectively.

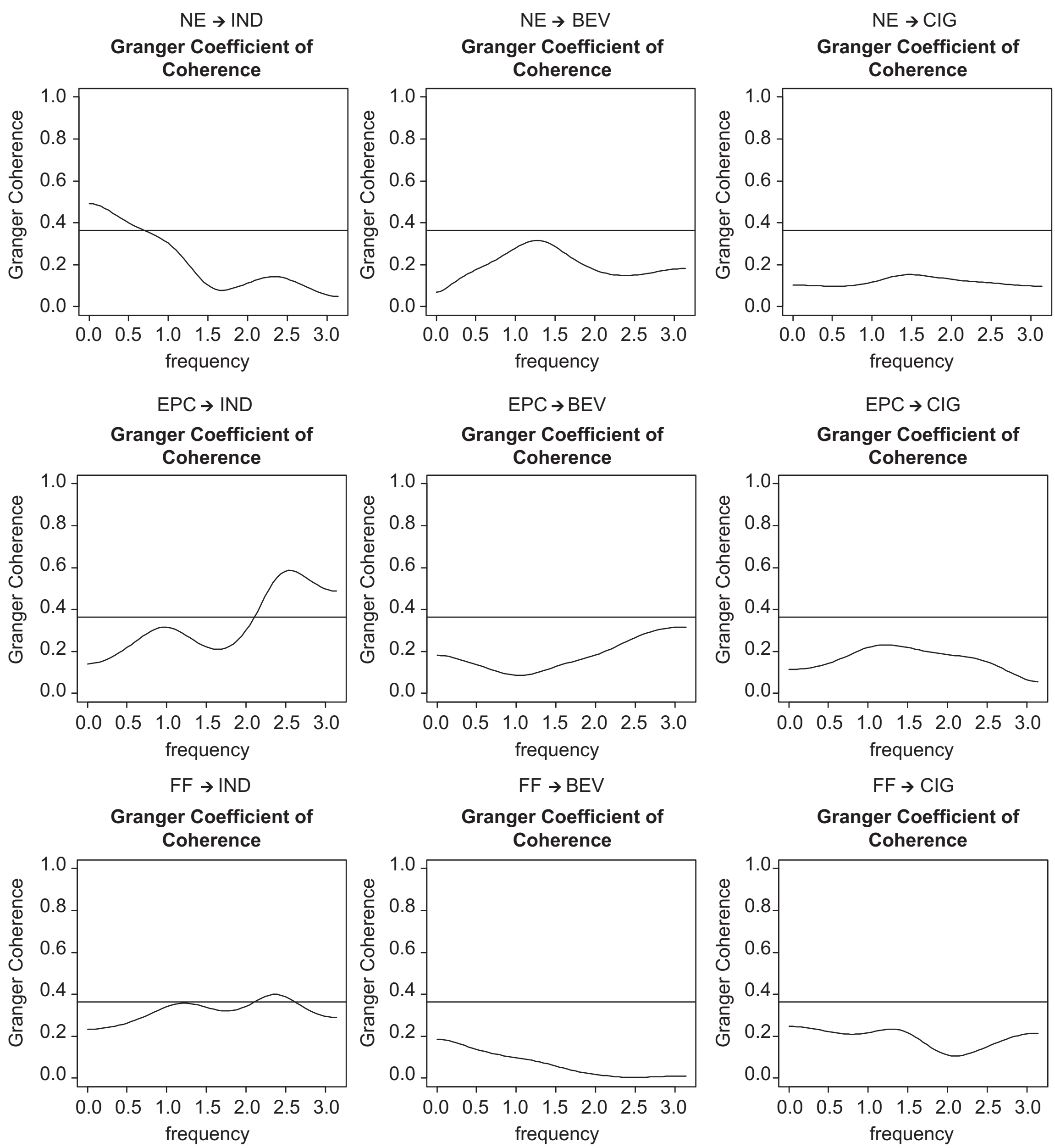

Fig. 5. Granger coefficient of coherence from energy demand to industrialization and industrialization to energy demand, using the Pierce framework. *Note*: The solid line represents the critical value at the 5% level for the test for no GC.

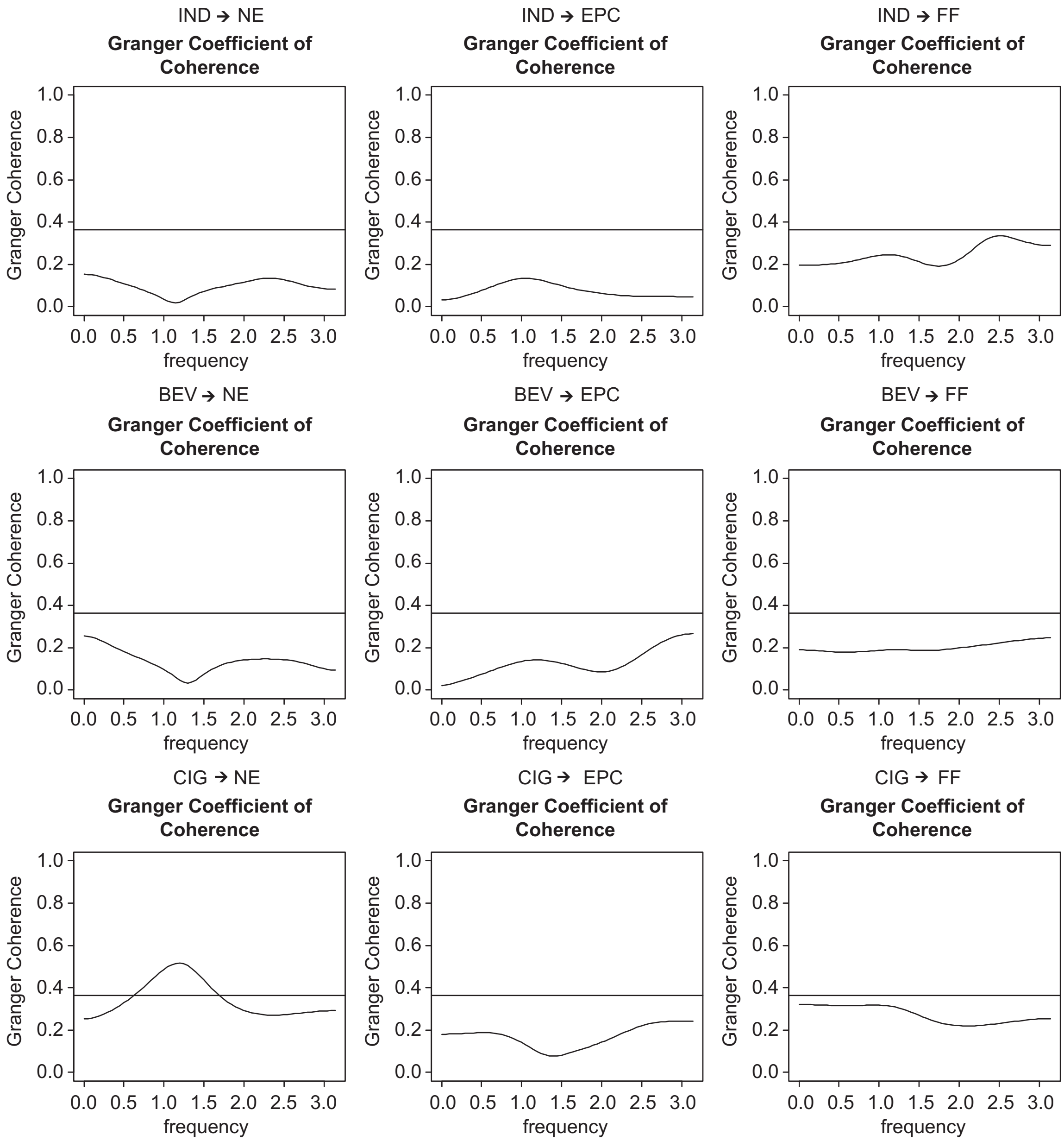

Fig. 5. (*continued*)

Fig. 5 shows for each of the three variables i.e. industrial growth (IND), beverages (BEV) and cigarettes (CIG) which are used as a proxy for industrialization and the three variables i.e. nuclear energy (NE), electric power consumption (EPC) and fossil fuel energy consumption (FF) which are used as a proxy for energy demand, Granger coefficient of coherence using the Pierce framework. This coefficient assesses, whether and to what extent the energy demand is Granger causing the industrialization at that frequency or vice versa.

Fig. 5 indicates insignificant impact of nuclear energy on beverages and cigarettes of Pakistan, whereas in case of industrial growth the Granger coefficient of coherence is significant corresponding to 10–36 years reflecting the long duration cycle. This implies that nuclear energy impact the industrial growth in the long-run and provides significant predictive power. Similar to the nuclear energy, the impact of electricity power consumption on the beverages and cigarettes is insignificant at all different frequencies. However the electricity power consumption Granger causes industrial growth in the short run reflecting 2–3 years cycle. The Granger coefficient of coherence reaches the maximum corresponding to 2.5 years. However in case of fossil fuel energy consumption to industrial growth, at frequency corresponding to five years, Granger coefficient reaches the 5% significance level but does not crosses the line whereas at frequencies corresponding to 2.5–3 years cycle it just crosses the line. This indicates the little impact of fossil fuel energy consumption on industrial growth. The impact of fossil fuel energy consumption on beverages and cigarettes is insignificant in the short and even in the long-run.

Fig. 5 further indicates the reverse causality i.e. at what extent the industrialization is Granger causing the energy demand at a particular frequency. The results show that there is an insignificant impact of industrial growth on nuclear energy, electricity power consumption and fossil fuel energy consumption of Pakistan at all different frequencies. This implies that there exists uni-directional relationship between nuclear energy and industrial growth running from NE to IND, uni-directional relationship between electricity power consumption and industrial growth running from EPC to IND and weak uni-directional relationship between fossil

fuel energy consumption and industrial growth running from FF to IND. In case of cigarettes, we found uni-directional relationship running from cigarettes to nuclear energy corresponding to 4–8 years cycle and no relationship between electricity power consumption and cigarettes or fossil fuel energy consumption and cigarettes. Overall, the results suggest that among all variables the most significant relationship in the long run running from nuclear energy to industrial growth and electricity power consumption to industrial growth in the short-run.

Fig. 6 shows for each of the three variables i.e. energy depletion (END), natural resources depletion (ND) and net forest depletion (NFD) which are used as a proxy for resource depletion and the three variables i.e. nuclear energy (NE), electric power consumption (EPC) and fossil fuel energy consumption (FF) which are used as a proxy for energy demand, Granger coefficient of coherence using the Pierce framework. This coefficient assesses, whether and to what extent the energy demand are Granger causing the resource depletion at that frequency or vice versa.

Fig. 6 indicates there is an insignificant impact of nuclear energy, electricity power consumption and fossil fuel energy consumption on all three proxy variables of resource depletion. This indicates that there is no direct Granger causality running from energy demand to resource depletion. However, on the other side, Fig. 6 also examines the reverse causality i.e. at what extent the resource depletion are Granger causing the energy demand at a particular frequency. There is insignificant impact of three proxy variables of energy depletion on electricity power consumption and fossil fuel energy consumption of Pakistan at all different frequencies. However, in case of Granger causality running from net resources depletion to nuclear energy, the Granger coefficient of coherence just crosses the line at the frequencies corresponding to 15–36 years cycle and the frequencies corresponding to 4–6 years cycle. The Granger coefficient of coherence attains the maximum of 0.4 corresponding to 5 and 36 years cycles, which indicates that there is a little impact of resources depletion on the nuclear energy in the short or long run. Similarly in case of

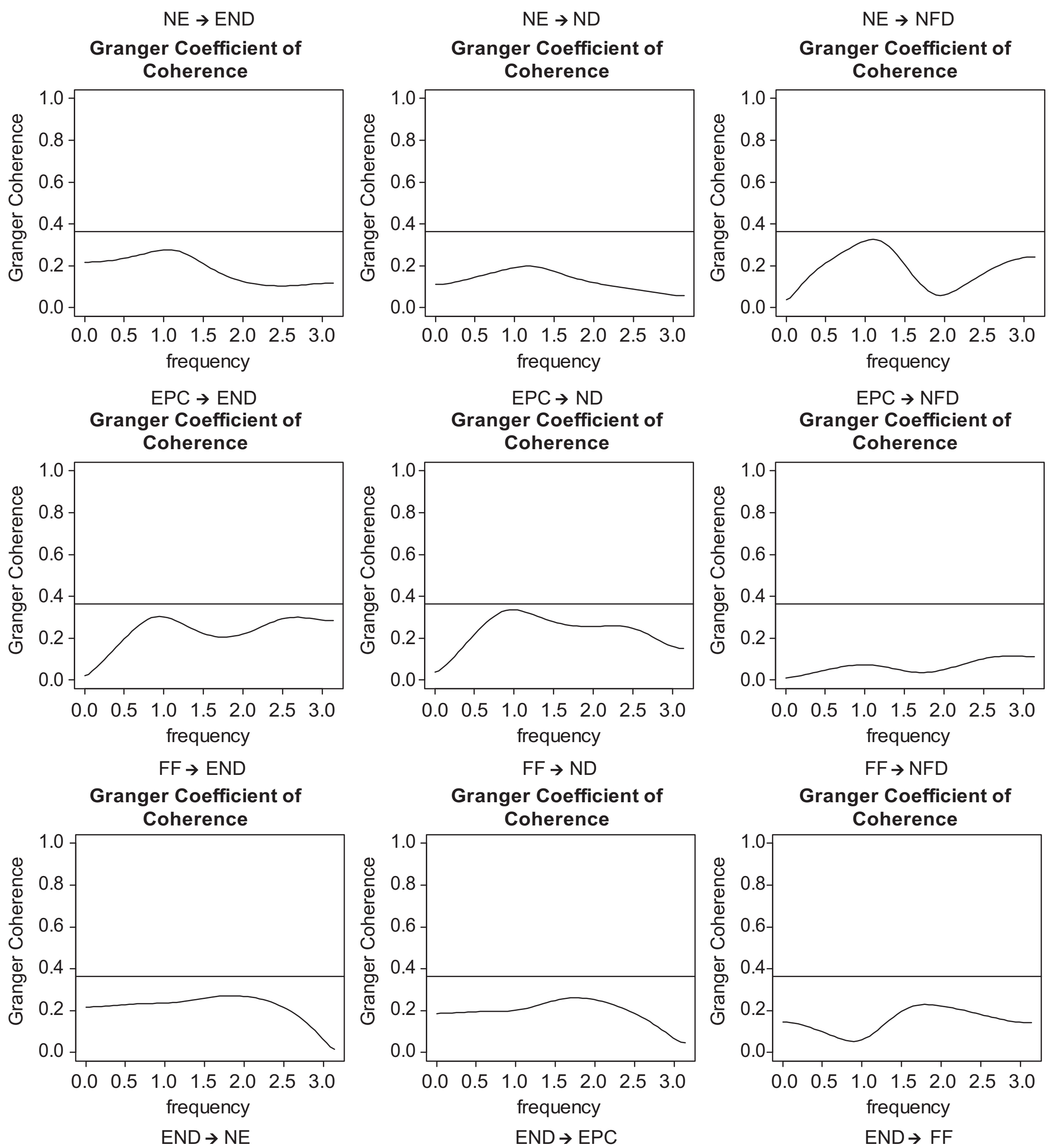

Fig. 6. Granger coefficient of coherence from energy demand to resource depletion and resource depletion to energy demand using the Pierce framework. *Note*: The solid line represents the critical value at the 5% level for the test for no GC.

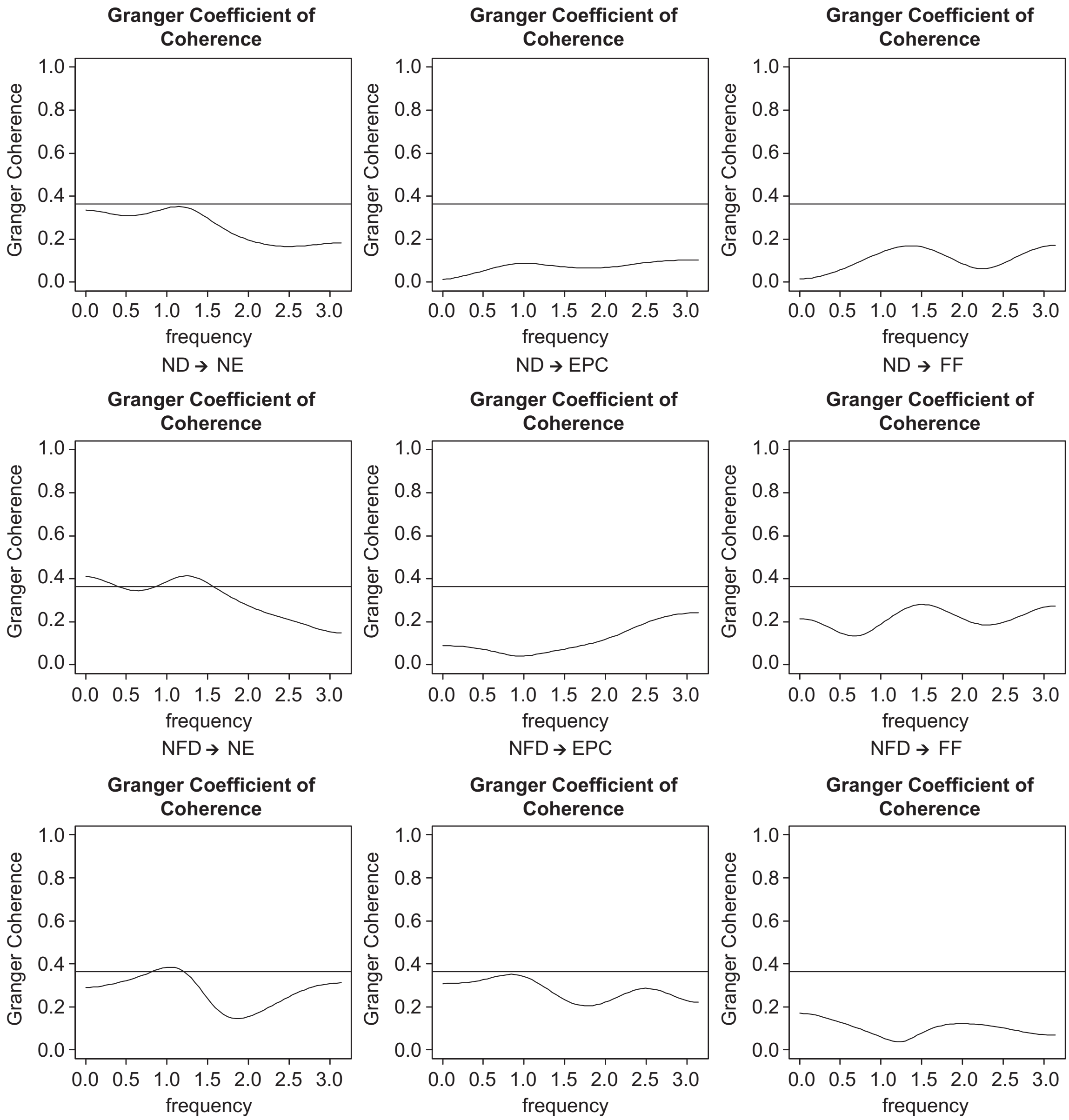

Fig. 6. (*continued*)

Granger causality running from net forest depletion to nuclear energy, the Granger coefficient of coherence just touches the line at the frequencies corresponding to 5–8 years cycle which again indicates little impact of net forest depletion on the nuclear energy in the short run. However there is no Granger causality running from energy depletion to nuclear energy. Overall, the result suggests that almost insignificant direct relationship between resource depletion and energy demand.

5. Conclusion

The objective of this study is to empirically investigate short-run or long-run causality between energy demand and four macroeconomic factors i.e., economic growth, industrialization, environmental degradation and resource depletion in Pakistan. Further, this study determines the direction of causality and finally strength of the relationship between the variables. The Granger causality test in the frequency domain using the Pierce framework has been employed. Secondary data pertaining to Pakistan from 1975 to 2011 on nuclear energy consumption, electricity power consumption, fossil fuel energy consumption, industrial growth, beverages, cigarettes, carbon dioxide emissions, population density, water resources, agricultural growth, manufacturing, services, energy depletion, natural depletion and net forest depletion has been considered. The result of the Granger causality running from energy demand to economic growth indicates that electricity power consumption is the most relevant variable as it has a significantly impact on all three variables of economic growth. There exists medium and long run impact of nuclear energy and fossil fuel energy on manufacturing and services sectors. The results show that all three proxy variables of energy demand Granger causes the manufacturing and services sector of Pakistan in short, medium or in the long run. The results indicate that there exists uni-directional relationship between GDP and electricity power consumption (EPC) running from GDP to EPC and the uni-directional relationship running from GDP to fossil fuel energy. The result also implies that there is no causal relationship between nuclear energy & agricultural growth, and fossil fuel energy and agricultural growth. However there exists a uni-directional

relationship running from electricity power consumption to agricultural growth in the medium-run. It is also concluded that there exists a unidirectional relationship of energy demand to manufacturing and services sectors of Pakistan at different frequencies. The results of granger causality between energy demand and environmental degradation indicates that there exists weak unidirectional relationship between nuclear energy and carbon dioxide emissions running from NE to CO_2 and no relationship between carbon dioxide emissions and electric power consumption of Pakistan. In the case of fossil fuel energy consumption, the results indicate that there exists weak bi-directional relationship between carbon dioxide emissions and fossil fuel energy consumption. The result designates that there is no causal relationship between nuclear energy and population density. However population density significantly Granger causes electric power consumption and fossil fuel energy consumption at all different frequencies. This implies that there exists strong bidirectional relationship between population density and electric power consumption and population density and fossil fuel energy consumption, respectively. The results show weak unidirectional relationship running from nuclear energy to water resources and no relationship between water resources and electric power consumption. However, the results suggest that among all variables of energy demand and environmental degradation, the most significant relationship exists between population density and electric power consumption and population density and fossil fuel energy consumption, respectively. The Granger causality results for industrialization and energy demand indicates that there exist unidirectional relationship running from nuclear energy to industrial growth, uni-directional relationship running from electricity power consumption to industrial growth and weak uni-directional relationship running from fossil fuel energy consumption to industrial growth. There exists uni-directional relationship running from cigarettes to nuclear energy in the short run and no relationship between electricity power consumption and cigarettes or fossil fuel energy consumption and cigarettes. The most significant relationship among all variables of energy demand and industrialization would be from nuclear energy to industrial growth in the long run and electricity power consumption to industrial growth in the short-run. The results indicate almost insignificant direct relationship between resource depletion and energy demand.

Energy needs are indelibly linked to Pakistan's economic and sustainable growth capabilities. Pakistan's have been in increasing in demand across the various areas of energy sources. With a growing economy and the desire for vast production and consumption across the country, the energy demands remain high. With energy shortages as a main challenge, the government is working tirelessly to ensure such problems are remedied [22]. Energy has been deemed the paramount source for industry which further links to the industrial pollution and eradication of the environment resulting into depleting natural resources. This depicts a very bleak picture but we have to be optimist about our existing potential and we have to do the best energy management to create the notion of *living with the just enough*.

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